Review of Carbon TerraVault (CTV) Responses to EPA's Questions about Construction and Plugging Procedures for Injection Well 357-7R at the CTV-Elk Hills Monterey Formation A1-A2 Class VI Project

In February 2022, EPA provided questions to CTV (*blue, italic text*) about the construction and plugging of the 357-7R injection well to inject CO_2 into the Monterey Formation A1-A2 Sands, submitted as part of CTV's Class VI permit application (dated August 30, 2021 and December 2, 2021) for the proposed CTV-Elk Hills Class VI geologic sequestration (GS) project. CTV provided updated operating procedures for the two wells to EPA on May 16, 2022. EPA's evaluation of how the update addresses its questions is presented in red below. Requests for revisions and additional information are presented in ***red, bold, and italic*** below. Previous responses that require no further information are not included in this enclosure.

Injection Well Construction

Attachment A--Narrative (referred to as The Narrative herein) and Attachment G describe the well construction design for Well 357-7R. Well 357-7R is an existing Class II pressure maintenance well that is currently permitted by CalGEM (California Geologic Energy Management Division) to inject up to 50 mmscf (million standard cubic feet) of CO_2 per day. The applicant states that Well 357–7R was constructed using CO_2-resistant materials and can meet operating conditions for the injection of CO_2. Well 357-7R was drilled in 1980; the Narrative A2 contains construction details regarding Well 357-7R.

Table 5 of the Narrative, corresponds to the casing specifications listed in Attachment G for Well 357-7R, pictured below. Attachment G also includes tubing and packer specifications for Well 357-7R, which are excerpted below. The tubing and packer specifications in Attachment G mostly correspond to Table 7 of the Narrative, however the packer burst strength (psi) and collapse rating (psi) differ between the documents.

Injection Well 357-7R Construction Details (Attachment G)

Casing Specifications

Name	Depth Interval (feet)	Outside Diameter (inches)	Inside Diameter (inches)	Weight (lb/ft)	Grade (API)	Design Coupling (Short or Long Threaded)	Thermal Conductivity @ 77°F (BTU/ft hr. °F)	Burst Strength (psi)	Collapse Strength (psi)
Conductor	20-60	20.000	19.5	52	H-40	Short	31	875	90
Surface	20-501	13.375	12.715	48	H-40	Short	31	1,727	740
Intermediate	20-3,517	9.625	8.835	40	N-80	Long	31	5,750	3,090
Long-string	20-8,990	7.000	6.184 6.276 6.366	29 26 23	N-80	Long	31	8,160 7,240 6,340	7,020 5,410 3,830

Tubing Specifications

Name	Depth Interval (feet)	Outside Diameter (inches)	Inside Diameter (inches)	Weight (lb/ft)	Grade (API)	Design Coupling (Short or Long Thread)	Burst strength (psi)	Collapse strength (psi)
Injection tubing	8,454	4.500	3.826	15.2	13CR-95	Long (premium)	12,450	12,760

Packer Specifications

Packer Type and Material	Packer Setting Depth (feet bgs)	Length (inches)	Nominal Casing Weight (lbs/ft)	Packer Main Body Outer Diameter (inches)	Packer Inner Diameter (inches)
Baker-Hornet, Ni plated	8,447	95.4	23-29	6.000	2.920

Tensile Rating (lbs)	Burst Rating (psi)	Collapse Rating (psi)	Max. Casing Inner Diameter (inches)	Min. Casing Inner Diameter (inches)
10,0000	8,000	8,000	6.466	6.184

All well materials noted in the tables above, in addition to the stainless-steel wellhead, are designed to be compatible with the CO_2 injectate and expected subsurface temperature and pressure regimes. The surface and downhole pressure gauge and logging tool specifications detailed in Tables 8-14 of the quality assurance surveillance plan (QASP) are mostly consistent with the well construction equipment and surface and subsurface temperature and pressure conditions. However, the surface pressure field gauges listed in Tables 10, 11, 12, and 14 of the QASP show a maximum calibrated working pressure of 3,000 psi, which is lower than the maximum surface injection pressure of 3,800 psi. The Applicant notes that the Class G Portland cement used to complete Well 357-7R, with cement to surface for each stage, has been used extensively in enhanced oil recovery injectors. Each casing string, except for the surface conductor, had cement returns to surface according to Figure 1 of Attachment G (reproduced below). The cement integrity is supported by data from existing wells and a cement bond log (CBL) in Well 357-7R. California Resources Corporation (CRC) has conducted MITs and standard annulus pressure test (SAPTs) every five years (no SAPT results were provided with the application materials, however). These tests will also be conducted prior to injection and are discussed further in the *Pre-Operational Testing* section of this evaluation.

Relevant geologic formation tops were noted in Figure 1 of Attachment G. The figure shows that the Base of the USDW is approximately 806 ft. TVD (true vertical depth), which is behind both the long string and intermediate casing. The surface casing is set to a depth of 501 feet; however, the average depth of the Tulare Formation (Upper and Lower) within the AoR is 600-2,500 ft (as reported on pg. 31 of the Narrative). EPA is requesting clarification of the depth of the Upper Tulare Formation (the lowermost USDW) in its questions on the geologic narrative, and CTV's response to this question will help confirm whether the surface casing is sufficiently deep to protect the lowermost USDW in accordance with 40 CFR 146.86(b)(2). (Based on the aquifer exemption record of decision for the Elk Hills Oil Field, the Upper Tulare is shallower than 400 feet.)

The perforations for Well 357-7R are shown at depths of 8,782 to 8,830 feet. The perforations are also described in the AoR and Corrective Action Plan; however, they are presented in depth relative to mean sea level, so confirmation that the depths are consistent is not possible.

According to Table 1 in *Attachment C – Testing and Monitoring Plan,* CTV will analyze the following CO_2 stream constituents based on established ASTM methods: O_2, N_2, CO, CH_4, H_2S, total hydrocarbons, total Sulfur, and CO_2 purity. It appears that H_2O was excluded from the CO_2 stream constituent analysis and will need to be included (a request was provided with the testing and monitoring evaluation). Additionally, the applicant does not state if the compatibility of the CO_2 stream and well construction components will be determined prior to well operation. Following the pre-construction measurement of

the composition, properties, and corrosiveness of the injectate, the well construction materials and cement will need to be reviewed based on the results of these tests.

Figure 1 of Attachment G, excerpted below, demonstrates the casing design for Well 357-7R. The well construction and cementing criteria described in the Narrative and Attachment G appear to be acceptable, except as noted in the questions below. However, the applicant did not provide a pre-operational testing plan to test the compatibility of the injectate with well construction materials.

The Emergency and Remedial Response Plan, described in Attachment F, provides a description of the events that may necessitate gradual or immediate shutdown of the well depending on the severity of the event. However, the applicant did not describe safety valves and automated shut-off devices in Attachment G.

The permit application Narrative (on pg. 2) notes that the "…continuously subsiding [San Joaquin] basin is a sediment filled depression that lies between the Sierra Nevada and Coast Ranges and is 450 miles long by 35 miles wide." The effects of subsidence on the mechanical integrity of injection wells has been cited as a concern in other California oil fields, and some operators have developed mitigation measures to relieve stress on the surface casing (e.g., via wellhead design that allows differential movement between the casings). Any design modifications to address the subsidence concern will need to meet the requirement that Class VI wells have cementing of the surface casing that extends to the surface.

Questions/requests for the applicant:

- *There are several discrepancies in the descriptions of Well 357-7R between tables 5, 6, and 7 of Attachment A and the tables on pages G2 and G3 of Attachment G. Please make the tables and the well bore diagram in Attachment G (if needed) consistent.*
  - *Attachment A, Table 5, and the Table on page G2 indicate that the intermediate casing in Well 357-7R is to a depth of 3,517 ft; on Table 6, this depth is 3,516 ft. The applicant removed this table from Attachment A and corrected the depth to 3,517 ft. The response is acceptable.*
  - *The conductor casing material is H-40 in Attachment A, Table 5 and Attachment G, and it is J-55 in Table 6. CTV removed the conductor casing grade from Table 1 and states that the conductor grade is not specified or relevant, but they did not explain why.*
  - *The surface casing material is H-40 in Table 5 and in Attachment G, pg. 2, and it is H-80 in Table 6. CTV changed the surface casing grade to H-40. The response is acceptable.*
- *Please confirm that the surface casing extends through the base of the lowermost USDW, as required per 40 CFR 146.86(b)(2). If it does not, please explain how the well will meet the requirements of 40 CFR 146.86(b)(2). A new Protection of USDW section on pg. 3 states that the surface casing is set and cemented within the USDW, not through the base of the USDW, and describes additional ways in which the surface casing is designed to protect the USDW. The applicant states that the intermediate string is set across the base of the USDW, and the annular cement will provide additional isolation. Cement bond logs in the 7" casing string indicate annular cement within and above the injection and confining zones.*
- *Is Well 357-7R equipped with real-time surface monitoring equipment and alarms and, if so, are these connected to automatic shutoff systems, as required at 146.88(e)(2)? If so, please describe*

these in Attachment G and describe how the safety valves and shut-off devices will be linked to the continuous injection and annulus monitoring system. If not, please update Attachment G to include these required components. Under "Alarms and Shut-off Devices" on page 5, the applicant states that real time monitoring and automated shut off controls will be added to the system. CTV is required to provide information for EPA to review before installing the equipment; these should be included on final as-built schematics of the well ; these should be included on final as-built schematics of the well. CTV states that they do not plan to install down hole shut off systems due to the lack of risk factors (e.g., high temperatures and pressures or corrosive materials). Additional clarification on why these risk factors are considered low is required.

- Please explain how the injection well's design will mitigate potential shallow compression resulting from land subsidence and comply with the requirement to cement to the surface. CTV describes in the Casing section on pages 2 and 3 that the well construction mimics other wells used in the area for injection with no operational issues related to structural strength. Additionally, the Construction, Operating and Plugging document (COP) states that subsidence has not been observed historically, and shallow compression is not anticipated as a concern. No evidence of this was provided, however.
- Please include alternative pressure monitoring devices to those listed in Tables 10, 11, 12, and 14 of the QASP with pressure field gauges with higher pressure ratings to function at the maximum surface injection pressure of 3,800 psi safely and reliably. CTV stated that the QASP will be updated to show equipment with pressure ratings of 5,000 psi. However, this change was not included in an updated QASP that CTV submitted on March 31.
- Please provide the most recent SAPT reports for the well. The most recent SAPT results from October 6, 2020, are provided on page 9 of the document, which shows the well maintaining pressure within the well annulus, demonstrating mechanical integrity. However, the SAPT was run for 20-30 minutes, and not the minimum of 60 minutes as described in the pre-injection testing in Appendix G2 submitted with the initial application materials. Because CTV will conduct an additional SAPT prior to injection, this response is acceptable at this point.

Follow-up Questions for the Applicant:

- ***Please clarify why the risk factors (temperature, pressure and corrosivity) are considered to be low and include further justification as to why the downhole shutoff system is not necessary.***
- ***Please confirm the base of the lowermost USDW. Please note the definition of USDW (40 CFR 146.3) below.***

  (USDW) means an aquifer or its portion:
  (1)(i) Which supplies any public water system; or (ii) Which contains a sufficient quantity of ground water to supply a public water system; and
  (A) Currently supplies drinking water for human consumption; or
  (B) Contains fewer than 10,000 mg/l total dissolved solids; and
  (2) Which is not an exempted aquifer.
- ***Please provide data or sources as evidence that lead to the determination that no subsidence has occurred in the area.***

- ***EPA requests that, for clarity, the conductor casing grade (which was reported as H-40 in the initial application) be included on Table 1. If this information was incorrect, please explain how the conductor casing is suitable for CO_2 injection.***
- ***Because the tubing grade was changed from 13CR-95 to L-80 CRA, please ensure that the coupons used in the corrosion monitoring section of the Testing and Monitoring Plan are revised accordingly.***
- ***Please update the QASP to show equipment with pressure ratings of 5,000 psi.***
- ***Please update Attachment G2 to include the pre-operation testing plan for the deep monitoring wells.***
- ***Please provide a pre-operational testing plan to test the compatibility of the injectate with well construction materials.***

Injection Well Pre-Operational Testing

The proposed pre-operational formation and well testing program for Well 357-7R required at 40 CFR 146.82(a)(8) and 146.87 is described in the Narrative and in Attachment G. Table 1 of the Pre-Operational Testing Plan for Well 357-7R identifies several tests that CTV indicates have been performed, and that these were provided. These include deviation checks, cement bond log, open-hole well logs, mechanical integrity test, SAPT, injection zone and confining layer core, reservoir conditions and fluid, injection zone and confining layer fracture gradients, and pressure testing. Attachment G also indicates that a SAPT, Temperature Log, and Radioactive Tracer Survey will be conducted prior to injection operations.

In the Testing and Monitoring Plan, CTV says that it "does not currently plan to complete pressure fall off testing" (pg. 10), given the extent of available information about the Monterey Formation A1-A2 Sands. However, a pressure fall off test must be performed prior to injection. See the testing and monitoring evaluation for additional discussion.

Cement bond logs and SAPTs of the injection wells are listed in Table 1 of the QASP (Summary of testing and monitoring). It appears that a SAPT was previously run and will be run prior to injection, but Attachment G does not indicate that a CBL will be run. Clarification on the well testing to be performed is needed.

Questions/Requests for the applicant:

- *The CBL provided with the Logging and Testing plan does not cover the entire injection and confining zones. Please provide a CBL that covers the entire injection and confining zones and explain the varying amplitude and seismogram signal throughout both zones. The applicant states that a full-well CBL will be completed during pre-operational testing and tubing removal. Please note that EPA will need to review and approve the results of the CBL prior to authorizing injection. Response is acceptable at this point.*

Follow-up Questions for the Applicant:

- ***Please provide an updated pre-operational testing plan that describes the tests identified in CTV's responses to questions in this document. For example, the plan should include: testing to confirm the plugback depth; a CBL along the full length of the well; an SAPT of an appropriate test duration; and MITs on monitoring wells 342-7R-RD1 and 327-7R-RD1.***

Objectives for Pre-Operational Testing

Based on the site characterization, AoR delineation modeling, and testing and monitoring evaluations, EPA has identified the following objectives for the planned pre-operational testing to address data gaps identified during the review. This information is summarized below (along with the planned tests that will address each data need) for reference and to clarify EPA's expectations for the updated materials that CTV must submit pursuant to 40 CFR 146.82(c).

Regional Geology and Geologic Structure

- Confirm hydraulic separation of the Monterey A1-A2 reservoir and the Monterey Formation A3-A11 reservoir (anticipated testing method: downhole pressure measurement via gauges).
- Perform pressure build-up testing as part of the Pre-Operational Testing plan (anticipated testing method: pressure build-up test).
- Confirm the fracture pressure of the injection and confining zones (anticipated testing method: step-rate test in each zone using a representative fluid).

Geochemistry/Geochemical Data

- Establish baseline geochemistry for the Monterey Formation, as well as the Tulare and Etchegoin Formations for all analytes to be monitored during injection operations, per the Testing and Monitoring Plan (anticipated testing methods: various geochemical analyses).

Seismic History and Seismic Risk

- Establish baseline seismicity (anticipated testing method: existing seismic network/historic seismicity database).

Facies Changes in the Injection or Confining Zones

- Determine if there are any heterogeneities within the Monterey A1-A2 that could affect its suitability for injection, including facies changes that could facilitate preferential flow (anticipated testing methods: pressure build-up test; also, core, log, seismic analysis have been performed).

CO_2 Stream Compatibility with Subsurface Fluids and Minerals

- Confirm the composition and water content of the CO_2 injectate as part of baseline sampling and verify that it will not react with the formation matrix (anticipated testing methods: various geochemical analyses).
- Confirm that the properties of the CO_2 stream are consistent with the AoR delineation model inputs (anticipated testing methods: various geochemical analyses).
- Confirm that the analytes for injectate and ground water quality monitoring are appropriate based on the results of geochemical modeling evaluation (anticipated testing methods: various geochemical analyses).

Confining Zone Integrity

- Test for changes in capillary entry pressure of the Reef Ridge Shale due to reaction of the shale with the injectate (anticipated testing method: mercury injection capillary pressure).

Injection Well Construction

- Following the pre-construction measurement of the composition, properties, and corrosiveness of the injectate, review the well construction materials and cement in the context of the results of these tests (anticipated testing methods: various geochemical analyses).

Well Stimulation

The application materials do not include a stimulation plan. 40 CFR §146.88(a) requires that all stimulation programs be approved by the EPA Director as part of the permit application and incorporated into the permit. If the initial permit does not include a stimulation program and the operator identifies a need for well stimulation later in the life of the project, a major permit modification would be necessary. EPA suggests that CTV consider preparing and including a proposed well stimulation program in the permit application. A generic stimulation program may be used for the pre-construction phase of the project.

Questions/Requests for the applicant:

- *To avoid the need for a permit modification if stimulation were to become necessary in the future, EPA requests that CTV prepare a draft stimulation plan. EPA can provide some additional guidance about the content of the plan, but anticipates that the plan should describe:*
  - *The stimulation fluids to be used, including any additives (e.g., corrosion inhibitors, clay inhibitors, biocides, complexing agents, or surfactants) or diverting agents; and*
  - *Step-by-step procedures that would be employed during stimulation.*

The updated Attachment I (Stimulation Plan) states that stimulation is not anticipated and that a plan will be submitted for approval should stimulation be required; it contains no general description of stimulation procedures. EPA has communicated with CTV that a stimulation plan submitted after the permit is issued will necessitate a modification to the permit. CTV has chosen to not include a stimulation plan at this point.

Monitoring Well Pre-Operational Testing

The pre-operational formation well testing program for monitoring wells 342-7R-RD1 and 327-7R-RD1 is described in Attachment G. These wells have been drilled and completed, and data from deviation checks and open-hole well logs were acquired. Demonstration of mechanical integrity will be conducted via mechanical integrity logs and tests prior to injection operations. A SAPT will also be conducted for each monitoring well. However, the type of MIT methods planned for mechanical integrity demonstration prior to injection was not discussed.

Questions/Requests for the applicant:

- *What specific MITs are planned for monitoring wells 342-7R-RD1 and 327-7R-RD1? The applicant says that they will address this in their pre-operational testing plan. MITs referenced in the original Attachment G include annulus pressure tests only. For existing wells that are proposed to be converted, an external MIT will be required.*

Follow-up Requests for the Applicant

- *Please include an external MIT in the pre-operational testing plan for wells that are proposed to be converted to monitoring wells*